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The Risk-Level Change of Dam Break Due to the Population Growth in the Dam Downstream

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Abstract: This research intends to evaluate the risk-level change of dam break due to the number of population growth rates in the dam downstream. The number of population growth rates in the dam downstream area causes the number of populations that is impacted by disaster risk. In this research, there is conducted the danger class classification of dam failure based on the increasing number of population growth rates. In this research, there is conducted a class classification about the dam failure based on the increasing of population growth rate. The methodology is started from data collecting such as PMF design flood that is used for analyzing the dam break to be obtained the flood boundary of the dam downstream area, Map of the Digital Elevation Model that is for knowing the topography of the dam downstream area, population data which is obtained from BPS that is for knowing the population growth rate so it can predict the population number until the life time of the reservoir, and the land use data that is for knowing the population growth rate in the downstream dam area so it can be known the development of residence until the life time of reservoir. Then there is carried out the evaluation and assessment, which is based on the number of risk populations. The result show that there are 6 dams with very high danger level of the downstream damage level and the classification assessment of dams is extreme such as the dams of Bintang Bano, Rotiklot, Napungette, Lolak, Kuwil, and Pandanduri. However, the other four dams also show a very high danger level but in the assessment classification of dam is high (not extreme) such as the dams of Batu Nampar, Kengkang, Sepit, and Jangkih Jawa. The result is hoped can predict the danger classification of dam failure during the life time of the reservoir. Additionally, it can give input to the policymaker in determining the risk classification of dam failure. Moreover, it can be as one of the inputs in developing the risk classification model of dam failure.

Keywords: dam break, risk, population growth, dam downstream.

大坝下游人口增长导致的溃坝风险等级变化

摘要：本研究旨在评估由于大坝下游人口增长速度的数量而导致的溃坝风险水平变化。大坝下游地区的人口增长速度决定了受灾害风险影响的人口数量。本研究根据人口增长速度的递增对溃坝进行危险等级划分。在本研究中，根据人口增长速度的增加对溃坝进行了分类。该方法从数据收集开始，例如用于分析大坝溃坝的保偏光纤设计洪水，以获得大坝下游区域的洪水边界，用于了解大坝下游区域地形的数字高程模型图，从 BPS 获得的人口数据，用

于了解人口增长速度，以便预测水库生命周期之前的人口数量，以及土地利用数据，用于了解下游坝区的人口增长速度，因此它可知居住地的发展直至水库生命期。然后根据风险人群的数量进行评估和评估。结果表明，有 6 座大坝的下游破坏等级危险等级非常高，大坝分类评估极端，如免登巴诺、罗蒂克洛特、纳蓬盖特、洛拉克、库维尔和潘丹杜里大坝。然而，其他四个水坝也显示出非常高的危险等级，但在水坝的评估等级中属于高级别（不是极端），例如峇都南巴、坑康、七月和强基爪哇的水坝。希望该结果能够预测水库寿命期内溃坝的危险等级。此外，它还可以为决策者提供信息，以确定大坝溃坝的风险分类。此外，它可以作为开发溃坝风险分类模型的输入之一。

关键词： 溃坝, 风险, 人口增长, 大坝下游.

1. Introduction

The dam break consequences in the dam downstream area include the possibility of the loss of life and property damage [1], which is closely related to the development level of the downstream area and the dimension of the dam or reservoir. The downstream areas with developed population crowded residences [2], economy, and industry activity centers have the possible consequence of a bigger fall victims [3] than in the undeveloped area.

The dam failure risk for the sustainable flood retention area was predicted by [4] in the Wider Greater Manchester Area. This research analyzed the design flood based on the inundation depth and flood discharge that had happened, then the impacted flood disaster was classified and recommended the handling way. The inundated area and the flood behavior were analyzed in [5] through the simulation of the Ciawi dam break. In this research, the inundation depth and design floods were calculated by analyzing the population increase in the dam location. Additionally, the hydro-dynamic of flood was also analyzed [6]-[8], the disasters were classified and the solution was recommended.

Based on the study of flood evaluation and dam safety [9], this study evaluated the population impacted by flood. This study analyzed the inundation depth, flood discharge, and the climate change factors besides the population increasing and the impacted population. However, this study did not classify the flood disaster that happened. There is some difficulty in it like the uncertainty of flood main characteristic (peak flow, duration, volume) [10]. The methods that are explained is not alpha and omega of hydrology [11]. The new method appears regularly and depends on the difficult numeric solution, which is not intuitive like the classic method, but it bargains an interesting perspective for the hydrologists.

Along with time, the dam downstream area will be changed due to the population growth, economy growth, and a land use change [12], for instance, as is

the increasing in population number so the residential area will also increase so it will cause the area function change into residences. The classification of dam break that exists today is momentary. It is said momentary because the classification of dam break is only carried out when the dam is being designed and constructed so it is not affected by the life time of the dam. Therefore, the classification of dam breaks [13] the criteria for addition due to the life time of reservoir [14]-[15], which is generally more than 50 years.

2. Materials and Method

2.1. Research Location

The research locations are in the 10 dams as follows:

1. Bintangbano dam, located in the Bangket Monteh village, Brang Rea district, Sumbawa Barat regency, Nusa Tenggara Barat Province-Indonesia
2. Rotiklot dam, located in the Futuketi village, Kakuluk Mesak district, Belu regency, Nusa Tenggara Timur province-Indonesia
3. Napungete dam, located in the Ilin Medo village, Waiblama district, Sikka regency, Nusa Tenggara Timur province-Indonesia
4. Lolak dam, located in the Pindol village, Lolak district, Bolmong regency, Sulawesi Utara province-Indonesia
5. Kuwil Kawangkoan dam, located in the Kalawat district, Minahasa Utara regency, Sulawesi Utara province-Indonesia
6. Pandanduri dam, located in the Sakra district, Lombok Timur regency, Nusa Tenggara Barat province-Indonesia
7. Batu Nampar dam, located in the Batu Nampar village, Keruak district, Lombok Timur regency, Nusa Tenggara Barat province-Indonesia.
8. Kengkang dam, located in the Sekotong Tengah village, Sekotong district, Lombok Barat regency, Nusa Tenggara Barat province-Indonesia
9. Sepit dam, located in the Pengembur village,

Praya Barat district, Lombok Tengah regency, Nusa Tenggara Barat province-Indonesia

10. Jangkik Jawa dam, located in the Mangkung village, Praya Barat district, Lombok Tengah regency, Nusa Tenggara Barat province-Indonesia

2.2. Method for Danger Level Determination

The danger level of a dam is determined based on the population number that are caught the risk. The risk population is all population in the dam downstream area who are threatened with the potential dam break. The risk population is analyzed as the cumulative number of people that are threatened in the whole part of the dam downstream. The risk population can be identified from the inundation map as a result of the dam break study.

Table 1 Number of people that are caught the dam break risk for each class of dam break [16]

Number of risk population (person/cumulative)	Distance from dam (km)				
	0-5	0-10	0-20	0-30	> 30
0	1	1	1	1	1
1-100	3	3	2	2	2

Table 3 Risk factors for evaluation of dam safety [16]

Risk Factor	Weight values in brackets			
	Extreme	High	Moderate	Low
Capacity (10^6 m^3) (FR_k)	> 1000 (6)	100 – 1.5 (4)	1.00 – 0.125 (2)	< 0.125 (0)
Height (m) (FR_l)	> 45 (6)	45 – 30 (4)	30 – 15 (2)	< 15 (0)
Evacuation demand (number of persons) (FR_e)	> 1000 (12)	1000 – 100 (8)	100 – 1 (4)	0 (0)
Level of downstream damage (FR_h)	Very high (12)	High (10) Rather high (8)	Moderate (4)	None (0)

2.3. Population Growth Rate

Population growth rate is a value that shows the level of population increasing per-year in the certain period. Population increase in a country in the certain period is expressed in percentage (%), and it is obtained based on the population census.

The factors that influence the population growth (demography factor) include: 1) births (natural); 2) deaths (natural); 3) migration (non-natural). However, the criteria for population growth number are as follows: 1) low if the number is < 1%; 2) moderate if the number ranges between 1 and 2%; 3) high if the number ranges between 2%-2.2%; 4) extreme if the number is > 2.2%

The value of population growth rate is expressed as the percentage of basic population. The population growth rate can be analyzed using three methods that are arithmetic, geometric, and exponential. The most frequently method used in the BPS is the geometric method with the interpretation as follows:

- LPP > 0, it means that the population increased in the t-year compared to the previous year.
- LPP = 0, it means that the population number did not change in the t-year compared to the previous year.

Number of risk population (person/cumulative)	Distance from dam (km)				
	0-5	0-10	0-20	0-30	> 30
101-1000	4	4	4	3	3
> 1000	4	4	4	4	4

Table 2 Consequence equality relation between dam downstream area and the dam break classification [16]

Consequence of downstream area	Dangerous level	Dangerous class
Small	Low	1
	Moderate	2
Big	High	3
	Very high	4

Table 1 presents the number of populations that caught the dam break risk for each class of dam breaks and Table 2 presents the consequence equality relationship between dam downstream area and the dam break classification.

Due to the life time of the reservoir, it is suggested to add a risk factor about the population increase and the land use change. Thus, the table of risk factors for evaluating the dam safety is given in Table 3.

$P_t, 0 < 100$, it means that population number decreased in the t-year compared to the previous year.

The population growth rate is a number that shows the level of population growth per-year in the certain period. To analyze the population growth rate is used the formulation as follows:

$$r = \left(\frac{P_t}{P_0} \right)^{\frac{1}{t}} - 1$$

where:

P_t - number of people in the r-year;

P_0 - number of people in the basic year;

t - time period;

r - population growth rate.

3. Results and Discussion

The population growth rate is for knowing the prediction of population number in the dam downstream area until the life time of the dam. The risk class regarding the encyclical (SE) [16] of Indonesia for each dam is presented as in Table 4 until 13.

Table 4 Class of dam risk regarding the dam encyclic (SE) for Bintang Bano Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification Assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Bintangbano	0	72	6	65.84	4	46,453	12	Very high dangerous level	12	34	Extreme
2	Bintangbano	10	72	6	65.84	4	60,769	12	Very high dangerous level	12	34	Extreme
3	Bintangbano	20	72	6	65.84	4	79,576	12	Very high dangerous level	12	34	Extreme
4	Bintangbano	30	72	6	65.84	4	104,306	12	Very high dangerous level	12	34	Extreme
5	Bintangbano	40	72	6	65.84	4	136,834	12	Very high dangerous level	12	34	Extreme
6	Bintangbano	50	72	6	65.84	4	179,640	12	Very high dangerous level	12	34	Extreme

Table 5 Class of dam risk regarding the dam encyclic (SE) for Rotiklot Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Rotiklot	0	42	4	2.67	4	1,966	12	Very high dangerous level	12	32	Extreme
2	Rotiklot	10	42	4	2.67	4	2,840	12	Very high dangerous level	12	32	Extreme
3	Rotiklot	20	42	4	2.67	4	4,128	12	Very high dangerous level	12	32	Extreme
4	Rotiklot	30	42	4	2.67	4	6,030	12	Very high dangerous level	12	32	Extreme
5	Rotiklot	40	42	4	2.67	4	8,850	12	Very high dangerous level	12	32	Extreme
6	Rotiklot	50	42	4	2.67	4	13,041	12	Very high dangerous level	12	32	Extreme

Table 6 Class of dam risk regarding the dam encyclic (SE) for Napungette Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Napungette	0	52	6	14.34	4	1,399	12	Very high dangerous level	12	34	Extreme
2	Napungette	10	52	6	14.34	4	1,749	12	Very high dangerous level	12	34	Extreme
3	Napungette	20	52	6	14.34	4	2,200	12	Very high dangerous level	12	34	Extreme
4	Napungette	30	52	6	14.34	4	2,795	12	Very high	12	34	Extreme

5	Napungette	40	52	6	14.34	4	3,602	12	dangerous level Very high dangerous level	12	34	Extreme
6	Napungette	50	52	6	14.34	4	4,730	12	Very high dangerous level	12	34	Extreme

Table 7 Class of dam risk regarding the dam encyclic (SE) for Lolak Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Lolak	0	58	6	21.85	4	19,915	12	Very high dangerous level	12	34	Extreme
2	Lolak	10	58	6	21.85	4	23,072	12	Very high dangerous level	12	34	Extreme
3	Lolak	20	58	6	21.85	4	26,851	12	Very high dangerous level	12	34	Extreme
4	Lolak	30	58	6	21.85	4	31,397	12	Very high dangerous level	12	34	Extreme
5	Lolak	40	58	6	21.85	4	36,882	12	Very high dangerous level	12	34	Extreme
6	Lolak	50	58	6	21.85	4	43,534	12	Very high dangerous level	12	34	Extreme

Table 8 Class of dam risk regarding the dam encyclic (SE) for Kuwil Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (million)	Weight	(X ₄)	Weight	(Y)	
1	Kuwil	0	64.5	6	23.37	4	58,051	12	Very high dangerous level	12	34	Extreme
2	Kuwil	10	64.5	6	23.37	4	66,868	12	Very high dangerous level	12	34	Extreme
3	Kuwil	20	64.5	6	23.37	4	77,915	12	Very high dangerous level	12	34	Extreme
4	Kuwil	30	64.5	6	23.37	4	91,965	12	Very high dangerous level	12	34	Extreme
5	Kuwil	40	64.5	6	23.37	4	110,101	12	Very high dangerous level	12	34	Extreme
6	Kuwil	50	64.5	6	23.37	4	133,894	12	Very high dangerous level	12	34	Extreme

Table 9 Class of dam risk regarding the dam encyclic (SE) for Pandanduri Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Pandanduri	0	42	4	28.94	4	33,689	12	Very high dangerous	12	32	Extreme

2	Pandanduri	10	42	4	28.94	4	40,924	12	level Very high dangerous level	12	32	Extreme
3	Pandanduri	20	42	4	28.94	4	50,981	12	Very high dangerous level	12	32	Extreme
4	Pandanduri	30	42	4	28.94	4	66,239	12	Very high dangerous level	12	32	Extreme
5	Pandanduri	40	42	4	28.94	4	91,058	12	Very high dangerous level	12	32	Extreme
6	Pandanduri	50	42	4	28.94	4	134,412	12	Very high dangerous level	12	32	Extreme

Table 10 Class of dam risk regarding the dam encyclic (SE) for Batu Nampar Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number if risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Batu Nampar	0	18	2	0.29	2	352	8	Very high dangerous level	12	24	High
2	Batu Nampar	10	18	2	0.29	2	400	8	Very high dangerous level	12	24	High
3	Batu Nampar	20	18	2	0.29	2	455	8	Very high dangerous level	12	24	High
4	Batu Nampar	30	18	2	0.29	2	517	8	Very high dangerous level	12	24	High
5	Batu Nampar	40	18	2	0.29	2	586	8	Very high dangerous level	12	24	High
6	Batu Nampar	50	18	2	0.29	2	666	8	Very high dangerous level	12	24	High

Table 11 Class of dam risk regarding the dam encyclic (SE) for Kengkang Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Kengkang	0	15	2	0.35	2	1854	12	Very high dangerous level	12	28	High
2	Kengkang	10	15	2	0.35	2	2194	12	Very high dangerous level	12	28	High
3	Kengkang	20	15	2	0.35	2	2612	12	Very high dangerous level	12	28	High
4	Kengkang	30	15	2	0.35	2	3113	12	Very high dangerous level	12	28	High
5	Kengkang	40	15	2	0.35	2	3738	12	Very high dangerous level	12	28	High
6	Kengkang	50	15	2	0.35	2	4522	12	Very high dangerous level	12	28	High

Table 12 Class of dam risk regarding the dam encyclic (SE) for Sepit Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Sepit	0	11.6	0	0.7	2	1,019	12	Very high dangerous level	12	26	High
2	Sepit	10	11.6	0	0.7	2	1,118	12	Very high dangerous level	12	26	High
3	Sepit	20	11.6	0	0.7	2	1,225	12	Very high dangerous level	12	26	High
4	Sepit	30	11.6	0	0.7	2	1,343	12	Very high dangerous level	12	26	High
5	Sepit	40	11.6	0	0.7	2	1,471	12	Very high dangerous level	12	26	High
6	Sepit	50	11.6	0	0.7	2	1,614	12	Very high dangerous level	12	26	High

Table 13 Class of dam risk regarding the dam encyclic (SE) for Jangkih Jawa Dam

No.	Name of dam	Life time (year)	Height of dam		Reservoir capacity		Number of risk population		Damage level in the downstream		Classification assessment based on the SE	
			(X ₁) (m)	Weight	(X ₂) (million m ³)	Weight	(X ₃) (person)	Weight	(X ₄)	Weight	(Y)	
1	Jangkih Jawa	0	17.5	2	0.89	2	856	8	Very high dangerous level	12	24	High
2	Jangkih Jawa	10	17.5	2	0.89	2	934	8	Very high dangerous level	12	24	High
3	Jangkih Jawa	20	17.5	2	0.89	2	1,021	12	Very high dangerous level	12	28	High
4	Jangkih Jawa	30	17.5	2	0.89	2	1,114	12	Very high dangerous level	12	28	High
5	Jangkih Jawa	40	17.5	2	0.89	2	1,216	12	Very high dangerous level	12	28	High
6	Jangkih Jawa	50	17.5	2	0.89	2	1,327	12	Very high dangerous level	12	28	High

Based on the dam risk classifications given in Tables 4-13 concerning the 10 dams under study, with regard to SE, the evaluation of the risk population number revealed six dams with the damage level in the downstream showing the very high danger level and extreme dam risk classifications. The dams in this condition are Bintang Bano, Rotiklot, Napungette, Lolak, Kuwil, and Pandanduri. However, the four other dams also show a very high danger level, but they are included in the high dam risk classification (not extreme). The dams in this condition are Batu Nampar, Kengkang, Sepit, and Jangkih Jawa. These conditions are caused by the population number change that are covered by the disaster risk.

Along with time, the dam downstream area will be

changed due to the population growth, economy growth, the land use change, and the increasing population number; therefore, the residential area will also increase and cause the area function change into residences. The classification of dam break that exists today is momentary because dam break was classified only at the time of the dam design and construction, when it was not affected by the life time of the dam.

4. Conclusion

Along with time, the dam downstream area will be changed due to the population growth, economy growth, and there is a land use change, for instance as is the increasing of population number so the residential area will also increase so it will cause the

area function change into residences. This study evaluated the population who are impacted by flood.

Based on the research result that is carried out to the 10 dams, which refers to the SE in Indonesia, there are 6 dams with the damage level in the downstream show a very high danger level and the evaluation of dam classification are extreme. The dams in this condition are Bintang Bano, Rotiklot, Napungette, Lolak, Kuwil, and Pandanduri. However, the 4 other dams also show a very high danger level, but there are included in the high dam assessment classification (not extreme). The dams in this condition are Batu Nampar, Kengkang, Sepit, and Jangkih Jawa.

The result is hoped can predict the danger classification of dam failure during the life time of the reservoir. Additionally, it can give input to the policymaker in determining the risk classification of dam failure. Moreover, it can be one of the inputs in developing the risk classification model of dam failure.

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